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DEGRADATION OF LASER OPTICAL SURFACES

By
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ATMOSPHERIC SCIENCES LABORATORY
WHITE SANDS MISSILE RANGE, NEW MEXICO

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ABSTRACT

Problems of optical surface degradation became apparent while measurements were being made with a laser. After examination, it was concluded that the defects fell into two categories - those caused by atmospheric dust and those resulting from the effects of cleaning solvents. A procedure is described which minimizes both of these problems.

CONTENTS

INTRODUCTION

When using high-power lasers, the appearance of imperfections on optical surfaces often becomes a problem because these imperfections degrade the operation of the device by adding energy losses. The effects considered here are attributed to the action of very high intensity radiation on surface contaminants such as dust particles or cleaning residue. We have been concerned with the degradation of sapphire resonant reflectors and laser rods used in a 100 MW Q-switched ruby laser and an erbium-doped glass pulsed laser. Under microscopic examination, it was observed that the imperfections of most concern in ruby, sapphire, and glass optical surfaces fall into two general classes: (1) spots and small circular indentations and (2) small conical craters.

DISCUSSION

The spots, under magnification, appear granular and protrude slightly as if material has been added to the surface. These spots were examined as to their chemical nature, using infrared absorption spectroscopy with a modified alkali halide pellet technique (1). This technique permits the removal of an individual spot and its identification. Calcite was specifically identified as a spot-forming material. Calcite is a relatively low-melting-point mineral (melting point 1339°C) and in the molten state is a relatively active, nonviscous liquid, capable of etching glass or sapphire.

The following example considered a 20-micron spherical sodium carbonate* particle illuminated by a ruby laser having an average beam energy of 0.01 Joule/mm^2. The calculations show that, with this ruby laser pulse, small carbonate particles can be easily melted by absorbing only 3.9% of the energy falling on them.

CALCULATIONS: A 20-micron spherical sodium carbonate particle having a specific gravity of 2.51 g/cm^3 weighs 10.5×10^{-9}g. Sodium carbonate has a specific heat of 0.256 cal/g°C, a boiling point of 851°C, and a heat of fusion of 66 cal/g. Starting at 20°C room temperature, 2.91×10^{-6} cal. are required to melt this 20-micron particle.

This particle, being illuminated by a ruby laser having hot spots of 1 Joule/mm^2, will have 7.51×10^{-5} cal. falling on it. For this sodium

* Calcite was not used as the example because the necessary physical constants are not available. Sodium carbonate is considered a representative case.

carbonate particle to melt, only 3.9% of the energy falling on it must be absorbed.

Calcite starts subliming at 898°C. However, the rate of sublimation is very slow relative to the time frame of a laser pulse. The particle of calcite would thus be expected to become molten and flow out across the optical surface (Fig. 1). From heat conduction into the optical surface, the calcite particle would solidify before any appreciable sublimation could take place. If it were in contact with an optical surface, the molten calcite would dissolve into the surface forming an etched spot. This solid solution would then be firmly fastened to the surface.

A later pulse traversing the same path would be expected to warm but not melt the calcite because the calcite is in direct physical contact with the optical surface (Fig. 1) allowing rapid thermal transfer. Because of the difference in thermal coefficients of expansion

$$\frac{\text{Calcite}}{\text{Sapphire}} = \frac{25.14\ (10^{-6})}{6.7\ (10^{-6})},$$

the spot would pull loose from the optical surface, leaving a circular indentation approximately 1 micron deep.

Under magnification, certain of the imperfections on glass surfaces appeared to be small craters. These had a conical shape with irregular edges. More of these crater-like imperfections appeared after each cleaning. As more of these craters formed, appreciable chips would be dislodged from the glass surface. It was supposed that when the surfaces were cleaned, water and/or other solvents such as acetone were absorbed into them (2). Such an absorbed liquid would require weeks to evaporate under low-humidity conditions. With any slight imperfections on the surface, the water will weaken a glass surface as much as 20% (3).

CORRECTIVE TECHNIQUES

The working area around a laser should be kept as clean as possible, free from dust and contaminants such as cigarette smoke, approaching clean room conditions as closely as possible, thereby minimizing the number of necessary cleanings.

If any dust is present and the spots form, most of these spots can be removed by cleaning a surface with distilled water and a mild solution of HCl. This should be done only if the physical nature of the optical surface

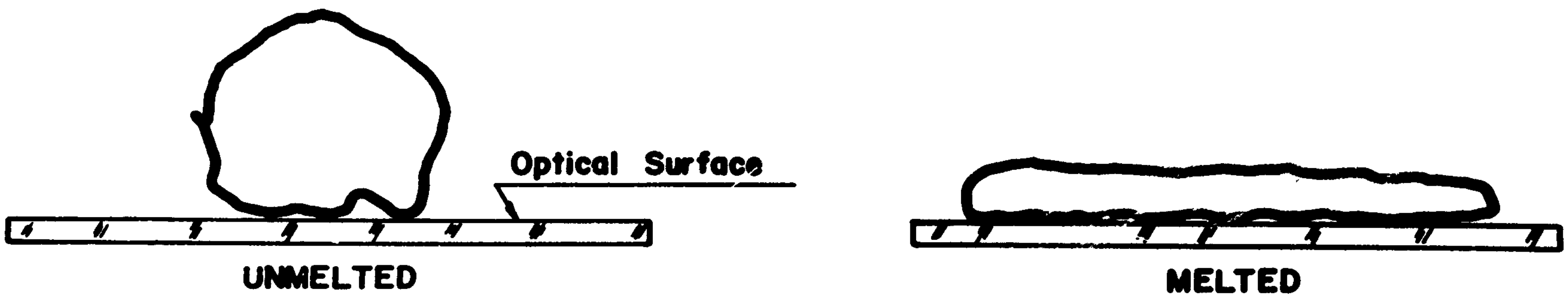

FIG. 1 SMALL CALCITE PARTICLE ON AN OPTICAL SURFACE AND MELTED ONTO AN OPTICAL SURFACE.

will not be damaged by acid. A second method was suggested * which consisted of starting a pulse laser system off with very low energy pulses and slowly increasing it until the required working level is attained. This will reduce optical surface problems. The dust is dislodged from the surface with the first weak pulses that are not capable of melting a dust particle.

In the second type of degradation, the craters are caused by liquids being absorbed a few microns into the glass surface during the cleaning operation, then producing miniature explosions when a strong laser pulse strikes the absorbed liquid. With the pulse laser starting off at low energy, the absorbed liquids slowly vaporize out of the surfaces, keeping the vapor pressure below that point necessary to cause the miniature explosions. Another solution to this type of degradation is a thorough vacuum drying at 100°C of the various optical components after each liquid cleaning. In the case of an erbium-doped glass rod, it was liquid cleaned, and without drying, was placed in its lasing cavity. After 100 shots, the lasing efficiency was down about 10%, and the rod ends were slightly pitted. After 400 shots, the lasing efficiency dropped approximately 50%, and the rod ends were badly pitted. Another glass rod was cleaned and vacuum dried. This rod, after several hundred shots, was still in excellent condition.

With the precautionary measures outlined here, the usefulness of optics in a laser system can be extended many times and more reproducible results obtained.

CONCLUSIONS

The types of degradation considered here fall into two general categories. The first category, which appears as spots and shallow indentations, is caused by low melting point mineral dust, such as calcite, dolomite, mirabilite, and gypsum, which are generally found in the atmosphere (4). The second category, appearing as small craters in the optical surfaces, is caused by liquids absorbed into the surface and exploding when the laser energy strikes the surface. With proper operational precautions as stated above, these problems can be minimized.

* Personal communication between James Mason of ASO, ASL, WSMR, and Dr. Martin Stickley of AFCRL, Bedford, Mass.

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13. ABSTRACT

Problems of optical surface degradation became apparent while measurements were being made with a laser. After examination, it was concluded that the defects fell into two categories - those caused by atmospheric dust and those resulting from the effects of cleaning solvents. A procedure is described which minimizes both of these problems.

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